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HEAD-UP VS. HEAD-DOWN: EFFECTS OF PRECISION ON CUE EFFECTIVENESS AND DISPLAY SIGNALING

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Two experiments were conducted to investigate the attentional effects in the presentation of cueing symbology with the use of a helmet-mounted display (HMD) relative to a hand-held display, and how reduced cue precision (experiment 1) and increased clutter (experiment 2) might modulate these effects. Participants were asked to detect, identify, and give azimuth information for targets hidden in terrain presented in the far domain (i.e., the world) while performing a monitoring task in the near domain (i.e., the display) using either a HMD or hand-held display. The results revealed overall cueing benefits in target detection performance, with slight decrements when cue imprecision was greater than 7.5°. More importantly, *undertrust* of the cueing data, induced by decreased precision, widened attentional breadth on trials after the automation unexpectedly failed.

INTRODUCTION

The ground soldier of the future will be asked to perform a multitude of tasks given various sources of electronic data. One option is to capitalize upon helmet-mounted display (HMD) technology and add to the HMD additional electronic information, regarding mission requirements, terrain, or the evolving aspects of the battle. The other is to provide similar information using a more traditional display format such as an electronic hand-held display. Here, the designer must consider the trade-off between two critical attentional variables: the costs to **focused** attention, related to the clutter of overlapping imagery in the HMD, and the benefits to **divided** attention, or information access, when information is presented head up, and the operator does not need to scan between the display and the outside world (Wickens, 1997; Wickens and Long, 1995). Fadden, Ververs, and Wickens (1998) conducted a meta-analysis of research that has compared the presentation of information head-up versus head-down in the context of air and ground vehicles. The analysis revealed that the costs of scanning, associated with head down presentation, generally outweigh the costs of clutter, associated with head up presentation, thereby generally favoring the latter (Fadden and Wickens, 1997; Martin-Emerson and Wickens, 1997; Ververs and Wickens, 1998b; Wickens and Long, 1995). However such research also indicates that the clutter costs become greater and more disruptive, as more information is added to the HUD (Ververs and Wickens, 1998b), and that these costs are also more strongly realized in detecting events in the far domain if those events are unexpected, and not salient (Wickens, 1997).

Hence, an important issue is how to present these data in a format that it can be most useful, and least disruptive of other tasks for soldiers on the move (National Research Council, 1997). The head-up presentation of data can conform to enduring characteristics of the real world, e.g., as in the experiments we report here, a visual cue used to direct attention to the location of ground targets. While this attention guidance can be presented on a head-down display as well, it appears less "natural" and direct in a head down position. We explore here the use of automated guidance as a function of display platform and consider how attention allocation may be modulated by the perceived reliability of the data.

The introduction of an automated system changes the nature of the work environment and information processing. In many cases, the human operator attends to the information provided by automation in an unpredictable and sometimes non-optimal manner (Parasuraman and Riley, 1997). Ultimately, one bases one's calibration of attention on the perceived reliability of an information source so that attention can be allocated in a more optimal fashion to more reliable sources of information so that they receive more processing and more weight in diagnosis.

In the presentation of cueing, it is relatively straightforward to predict that directly overlapping the cue on a target will provide faster and more accurate cueing than a less direct means of guiding attention – e.g., an arrow pointing to the cue (Egeth and Yantis, 1997; Jonides, 1981). However, such guidance may induce *attentional tunneling*, in which operators over-allocate attention to the cued location, and fail to attend to other important but uncued sources of data (Ockerman and Pritchett, 1998; Yeh, et al., 1999). This misallocation of attention may result from an *overtrust* in the automated guidance, fostered by an assumption that high registration accuracy signals the display of highly reliable data. Conversely, one may suppose that the farther the cue is from the target, i.e., the lower the **precision** of the cue, the less the user trusts the automated information and the wider the attentional breadth around the cued location. In some cases, the cue may be unreliable and fail to highlight an object or

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target that it was designed to highlight. The consequences of (un)reliability may be the tendency for the user to assume the cueing information is correct, attend to the data, and follow it "down the garden path" even when it should not be followed (Wickens, Conejo, and Gempler, 1999).

The purpose of these two studies was to examine the attentional implications of presenting attention guidance information on head up (HMD) or head down (hand held) displays, and examine how reduced cue precision (experiment 1) and increased clutter (experiment 2) might modulate these effects.

EXPERIMENT 1: PERCEIVED RELIABILITY IN CUE PRECISION

Methods

Sixteen military personnel took part in the experiment; they were paid $7.00/hr. The experiment was conducted in an immersed virtual reality environment known as the CAVE using head-tracked shutter glasses. The CAVE presented a field of view of 270° surrounding the soldier. The displays were created from static two-dimensional rendering of three-dimensional images depicting hilly terrain. Target stimuli, consisting of tanks, soldiers, land mines, and nuclear devices, were camouflaged in the terrain.

Figure 1 presents an example of the HMD-depicted scene.

Figure 1. HMD scene. The secondary task and cueing reticle are shown to the left, along with a conformal heading scale that overlays the true horizon.

The symbology displayed on the HMD consisted of a cueing arrow, lock-on reticle, heading tape, and a secondary task. This information was presented monoscopically to one eye. Cueing symbology, presented for half the targets, consisted of an arrow pointing in the direction of the target object based on the subject's current head position. Once the target was present in the forward field of view, the cueing arrow turned into a reticle, which was a box with four crosshairs.

Figure 2 presents a picture of the hand-held display.

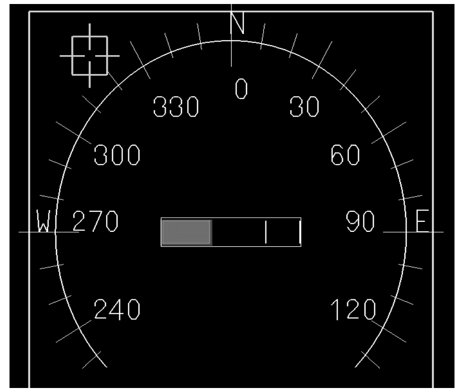

Figure 2. Hand-held display.

Symbology on the hand-held display provided participants with a simple diagram of the world, heading information, cueing information, and the secondary task. The information on the hand-held was presented non-conformally. That is, the compass did not rotate with the direction of orientation of the HHD.

Soldiers performed a series of tasks with the primary task being that of target detection. They scanned the display to search for one of four targets (tank, soldier, land mine, or a nuclear device). The tank, soldier, and land mine were presented 90% of the time (30% each) and were *expected*. The nuclear device was presented only 10% of the time, and was thus considered unexpected. Unlike the other targets, the nuclear device was never presented alone but was always presented concurrently with either a tank or soldier. Soldiers were instructed that reporting the nuclear device took precedence over the detection of all other targets. While searching for the targets, participants were instructed to perform a secondary task requiring them to monitor an analog radio frequency display (shown at the bottom of the HMD in Figure 1), which gradually drifted and provided data as to how close the enemy was in tracking their frequency.

Participants were presented with one practice block and ten experimental blocks; the latter contained a set of twenty search trials (six each of tanks, soldiers, and land mines, and two nuclear devices). Cueing was available to aid the task for half the soldiers, and half the land mines. In each block of trials, half of the cues were precise (indicated with solid lines) and half were imprecise (dashed lines) appearing in random sequence with the degree of imprecision alternated between blocks. Participants were informed as to the level of precision reliability in advance of each block. An unexpected target was presented twice in each block of trials; it was never cued directly but presented concurrently with a target object that was cued (once precisely and once imprecisely). Thus, the measurements of attentional costs for both imprecise and precise cueing was assessed when the cue itself was on the target. Precision was manipulated at one of three levels: extremely precise (0°-7.5° from the target center); partially degraded (7.5°-22.5° from the target center); and poor (22.5°-45° from the target center).

An 11th block of trials was presented to explore the effects of trust in the cueing automation. In this last block, several

catastrophic cueing errors occurred in which the cue was presented further than 90° from the target.

Results

The data were examined to determine the effects of cue precision on trust calibration and attention allocation in a target detection task. For the purposes of simplifying the discussion of the data, three target classes were formed from the data for the tanks, soldiers, land mines, and nuclear devices. First, the target objects were classified in terms of expectancy, with the tanks, soldiers, and land mines being expected, and the nuclear device unexpected. Second, prior research had revealed that the land mine, with its smaller visual angle than the tank and soldier was less visible and more poorly detected (Yeh, et al., 1999). Therefore it was considered the low salience target. Finally, the data for the tanks and the soldiers, both expected and highly salient objects, showed similar trends; consequently, their data were collapsed. Hence, the three target classes were: (1) expected, high salience (tanks and soldiers); (2) expected, low salience (land mines), and (3) unexpected (nuclear devices).

A 2 (display) x 2 (cueing) within subjects ANOVA conducted on the response time data for the high salience soldiers and low salience land mines revealed benefits in the detection of cued targets relative to uncued targets, $F(1, 15) = 221.59$, $p < 0.01$. In order to determine the effects of cue precision, a 2 (display platform) x 4 (cue type: perfect, degraded, poor, uncued) x 2 (target type: high salience vs. low salience) within subjects ANOVA was conducted. The results are presented in Figure 3.

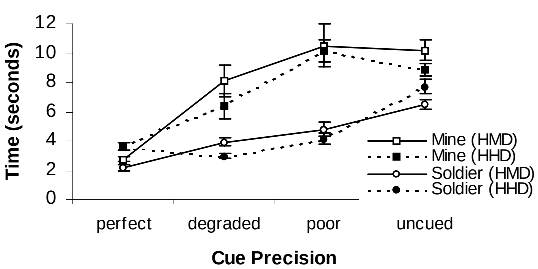

Figure 3. Effects of cue precision.

Not surprisingly, there was a main effect of cue precision $F(3, 45) = 47.42$, $p < .01$. Spatially accurate cues led to faster detection performance than those with less precision, $F(3, 45) = 47.42$, $p < 0.01$, and response time increased as cue precision was degraded (perfect vs. degraded, $F(1,15) = 26.95$, $p < .01$; perfect vs. poor, $F(1,15) = 78.61$, $p = .0000$). A significant target type x cue precision interaction, $F(3, 45) = 10.17$, $p < 0.01$, suggested that the reduction in cue precision hindered the detection of low salience targets (the top two lines in Figure 3) to a greater extent than high salience targets and indeed the "poor" level was better than no cueing at all, for the high salience (soldier) targets.

Detection of the expected targets was of high accuracy (approximately 95%) and was not significantly affected by the different display types or cue types. In order to better assess whether attentional breadth was widened by decreased cue precision, we examined the cueing effects on the detection of the unexpected uncued object (the nuclear device) in the same scene. Here, the unexpected nuclear devices were always presented concurrently with an expected target, and the expected target in this case was always cued accurately, though half the time, the cue was dashed, signaling imprecision. The data revealed that the unexpected targets were detected only 50% of the time, and that this detection was significantly lower than that of the expected targets (detected approximately 95% of the time), $F(2,30) = 110.20$, $p < .01$, but that this detection was not affected at all by cue precision. Hence, our attempts to broaden attentional breadth using explicit display characteristics was seemingly unsuccessful.

While platform (HMD vs hand-held display) did not significantly affect detection of the unexpected target, there was a non significant ($p=0.15$) trend for these targets to be less accurately detected with precise cueing, when the cueing was presented on the HMD, rather than the hand-held display.

More interestingly, though, we discovered that attentional breadth could be widened with *implicit* display characteristics. In the last block of search trials, several catastrophic cueing errors, were presented such that the cue was placed at a location greater than 90° from the target. On these trials, the target was eventually found, but with very long detection times (101.4s for the hand-held display and 56.8s for the HMD; the difference between the two display platforms was significant, $t(7) = -3.58$, $p = .006$). It is also important to note that two of the participants detected false targets at the cued location when in fact nothing was presented at location.

More importantly, was the behavior exhibited immediately following the 1st erroneous trial when a cued object was paired with an uncued high priority target. While previous analysis reveled a 50% rate of detection for the unexpected object, after the automation failure, the unexpected target was detected 100% of the time when using the hand-held display and 82% of the time with the HMD; this increased detection rate was significant for the hand-held display, $t(7) = 5.23$, $p = .001$, and showed a non-significant trend for the HMD, $t(8) = 1.32$, $p = .22$. Thus, the appearance of the catastrophic failure seemed to "diffuse" attention and neutralize the cost of attentional narrowing.

Clutter-Scan Trade-off. A significant display x cueing interaction, $F(1, 15) = 15.70$, $p < 0.01$, revealed a 1s advantage for the detection of cued targets when the symbology was displayed on the HMD than on the hand-held display, but no display advantage for uncued targets. In fact, when these uncued targets were also not salient (the land mines), their detection with the HMD was actually 2 seconds slower than with the hand-held display. That is, the clutter costs of the HMD dominates when the target is not salient, but the scanning costs of the head-down display dominate when the target is more salient.

Discussion

Our attempts at broadening attention were not successful in a way that might have been predicted. Cue imprecision led to progressively greater cost in the time of detection of less salient targets (land mines), which being less visible in the periphery (smaller useful field of view), suffered more as this peripheral area was widened. While this cost for imprecise cueing was harmful for the low salience targets, the imprecise cueing still provided some speed benefit relative to the uncued condition, for the more salient target type, even when error was as great as 45° from the center of the target.

The attentional costs reported by Yeh, et al. (1999) were replicated here, as shown by the reduced number of detections of the unexpected target (the nuclear device) when compared to the accuracy with which expected targets were detected. Furthermore, this cost was modulated by the catastrophic failures in the intelligent guidance, which eventually resulted in *undertrust* of the automation. When participants' trust was betrayed, we observed extremely long detection times as a consequence (Parasuraman and Riley, 1997; Lee and Moray, 1994). The initial system failure was unexpected, and we observed long search times in the cued regions, as would be expected from operators who have built trust in a system over time (Parasuraman and Riley, 1997; Lee and Moray, 1994). The appearance of this catastrophic failure then widened attention on subsequent trials and neutralized the attentional cost; the higher detection rate of the unexpected event (91% after vs 50% before) thereby suggesting that participants employed a different search strategy when a lower level of trust was attributed to the automated cueing system. This strategy resulted in them being less immediately drawn to the cue, less likely to report a target there, and more likely to search carefully elsewhere for the higher priority nuclear device.

The reduction of scanning with the use of HMD, aided detection of accurately cued targets, but there was some evidence for HMD clutter costs in the detection of non-salient, uncued targets, as well as those targets that were unexpected. When targets were uncued, there was evidence of a clutter-scan trade-off such that accurately cued targets were found faster than uncued targets, with the fastest average detection times and greatest cueing benefits observed while subjects were wearing the HMD. The improved performance with HMD-based cueing may be attributable to two reasons: (1) the ego-referenced HMD cueing was more precise in presenting the target location since the accurate cueing was usually superimposed directly on top of the target, thus providing the exact x and y location of the target, while the HHD lacked information concerning the target location in the y-axis; (2) the head-up presentation of cueing reduced vertical scanning as was required with the head-down display.

The information presented on the displays used in Experiment 1 was relatively sparse. The availability of an HMD in today's military as well as many other environments in which "wearable computers" are designed to present information superimposed on the outside world would allow designers to display not only cueing information, but also a host of other information. We wanted to examine the attentional issues in the presentation of complex data at a head-up location. In particular, we wanted to determine how attention is modulated by the display of non-conformal complex imagery in the context of the clutter-scan trade-off. This was the goal of Experiment 2.

EXPERIMENT 2: CLUTTER-SCAN TRADE-OFF IN AN INFORMATION-RICH DISPLAY

Methods

Eight military personnel participated in the experiment. The experimental design and target detection tasks were identical to that used in Experiment 1, with the following exceptions: (1) Cueing was available but was presented with only 45° of precision. (2) To better examine the nature of the clutter-scan trade-off, more complex symbology that that used in previous studies was presented on the display. This is shown in Figure 4.

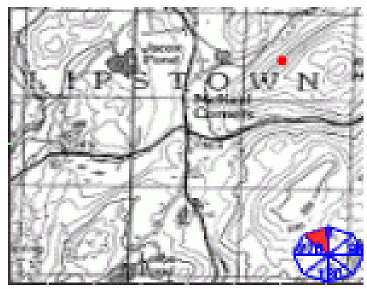

Figure 4. Symbology

This imagery presented a translucent map contour containing a dynamic element, which was used for a monitoring task to be performed in conjunction with target detection. Further details can be found in Yeh, et al. (2000).

Results

A main effect of display, $F(1, 7) = 6.84$, $p < 0.05$ suggested an advantage for the hand-held display, and a main effect of cueing, $F(1, 7) = 21.14$, $p < 0.01$ suggested that the presentation of a cue facilitated target detection. The significant interaction between display and cueing, $F(1, 7) = 7.75$, $p < 0.05$, suggested that the cost of superimposing symbology was minimized when the target to be searched for was cued. This cost of HMD clutter was enhanced to 6s when the uncued target was not salient (the mine).

More interesting was the accuracy data. Here, the data reveal significantly lower accuracy in detecting the unexpected object, $F(1, 7) = 22.58$, $p < 0.001$, but contrary to prior research, no effect of display location, $F(1, 7) = 0.05$, $p = 0.83$ nor cueing, $F(1, 7) = 0.92$, $p = 0.37$. Taken collectively, the data suggest that superimposing imagery head-up, as it was implemented in the current paradigm, imposed a significant cost of clutter, and this cost was reflected in response time, rather than accuracy.

In order to assess the costs of scanning, the data were examined to assess how well participants were able to perform the monitoring task (as measured by response latency) while

searching for targets as a function of display location. Here, a 2 (display) x 2 (cueing) ANOVA showed no accuracy differences attributable to display, $F(1, 7) = 0.65$, $p = 0.44$, nor cueing, $F(1, 7) = 0.19$, $p = 0.67$, but revealed a significant display x cueing interaction, $F(1, 7) = 9.61$, $p < 0.05$, suggesting that cueing diverted attention away from the secondary task and degraded its accuracy only when the cue (and secondary task) were presented on the HMD.

Discussion

Although target detection performance was aided by cue presentation, regardless of display location, participants were better able to detect the target when information was presented head-down with no loss in performance in the monitoring task. Hence, the data already show the detrimental costs of clutter, replicating findings reported in the HUD literature (Ververs and Wickens, 1998), even though the symbology presented in the current study was only a very small subset of the information that may be displayed to the ground soldier of the future. Despite the translucent characteristics of the imagery, the high level of detail used to present the topographical data likely reduced the visibility of information in the far domain that appeared behind the imagery to a greater degree than that of any HUD symbology, as in the studies reviewed by Fadden, et al. (1998, 2000) or of the very simplified imagery employed by Yeh, et al. (1999). This is a cost associated with any head-up presentation of dense cluttered imagery.

GENERAL DISCUSSION

The results are encouraging with regards to attentional cueing; while the lowest levels of cue precision did not benefit performance in the detection task relative to the uncued condition for targets with low salience, imprecise cues still proved beneficial in the detection of the more salient targets. Potentially systems that can reduce search space within a diameter of 90 degrees or less could provide benefits for target detection, with either display platform.

When participants' trust of the automation was betrayed (through the presentation of catastrophic cueing errors), we observed extremely long detection times because of the effects of overtrust in the system automation. More importantly, the catastrophic loss in trust mitigated the attentional costs of cueing; the higher detection rate of the unexpected event (91% after, versus 50% before) implied that participants employed a different search strategy as a consequence of decreased trust in the cueing system. This strategy resulted in them being less immediately drawn to the cue, less likely to report a target there, and more likely to search carefully elsewhere for the higher priority nuclear device.

As the head-up presentation of tactical data is further examined, it is important to evaluate methods for decluttering the information (e.g., by moving information out of the forward field of view when it is not necessary or "erasing" it temporarily) and the potential consequences for doing so, e.g., the cost of failing to detect a change in the "decluttered" domain or the additional manual control and cognitive requirements imposed by selecting different data bases to be displayed or removed (Wickens, Kroft, and Yeh, 2000).

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